Status Report on the JAERI AVF Cyclotron

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Abstract

The JAERI AVF cyclotron has been used for experiments since January 1992. The routine operation of the cyclotron began in September 1992. The total operation time amounted to 18,000 hours in August 1997. We have delivered thirty-three kinds of ion beams and cocktail beams ranging from proton to xenon with energies of 10 - 520 MeV. This paper reports status on performance and operation of the cyclotron and recent development.

1 Introduction

The TIARA (Takasaki Ion Accelerators for Advanced Radiation Application) facilities have been constructed at Takasaki Radiation Chemistry Research Establishment of Japan Atomic Energy Research Institute (JAERI) since 1987 for R&D in materials science and other irradiation purposes. The facilities consist of an AVF cyclotron[1][2] and three different types of electrostatic accelerators: a 3 MV tandem accelerator, a 3 MV single-ended accelerator and a 0.4 MV ion implanter.

The applications of the cyclotron require that many kinds of light and heavy ions can be accelerated in a wide range of energies. To meet the requirement, continuing efforts have been made on new beam development, improvement of beam extraction and transmission, etc.

The operation of the AVF cyclotron for experiment was started from 1992 in daily operation mode on a trial base. The weekly continuous operation was started from September 1992. The total operation times amounted to 18,000 hours in August 1997.

2 Present Status

2.1 Operation

The yearly operation time is divided into three beam-time periods, each of which consists of 11 weeks. The weekly operation is usually carried out continuously from Monday morning till Friday evening. Regular over-haul is carried out for 4 weeks in summer.

Operation statistics of the cyclotron during past 5 years are shown in Fig.1. The operation time for visitors use with charge, mainly used for irradiation test of semiconductor devices for space, is increasing every year. The accelerated particles and their beam time are also shown in Fig. 2.

In order to meet the requests from many groups of researchers, the accelerated particles, their energies and the beam courses were changed as shown in Fig. 3.

2.2 Maintenance and Status

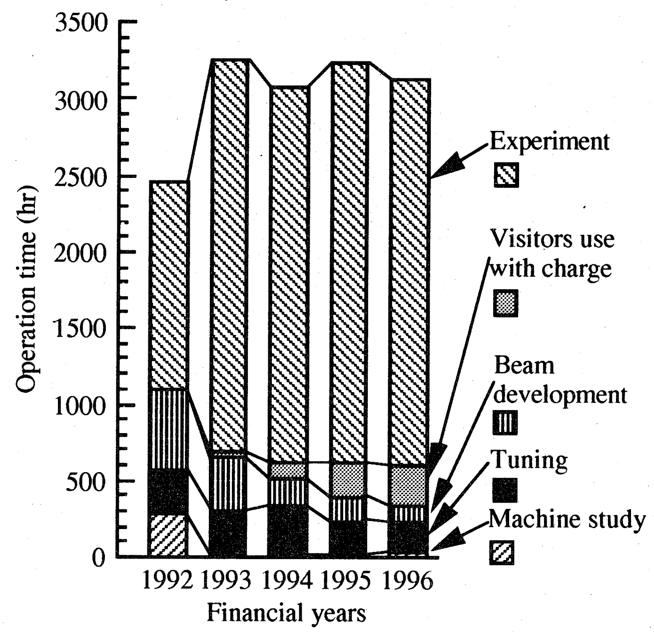

Fig. 1 Statistics of the cyclotron operation from 1992 to 1996.

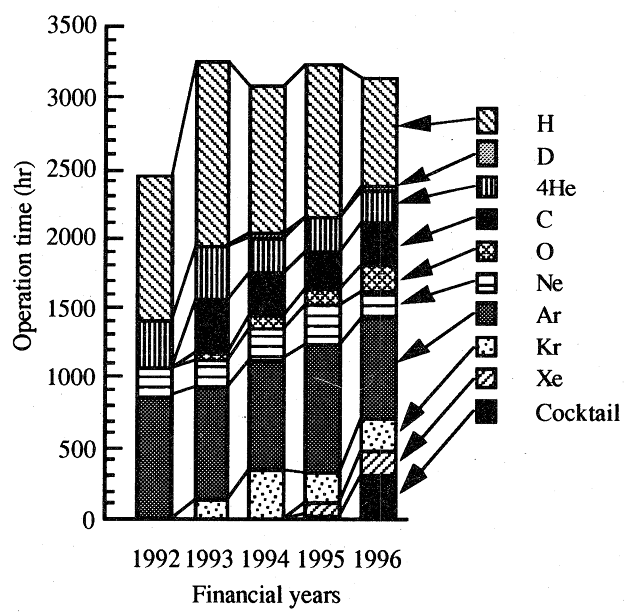

Fig. 2 Statistics of the accelerated particles and their beam time from 1992 to 1996.

It is clear that the power supplies for the magnets, constructed nearly 10 years ago, cannot keep the regulation sta-

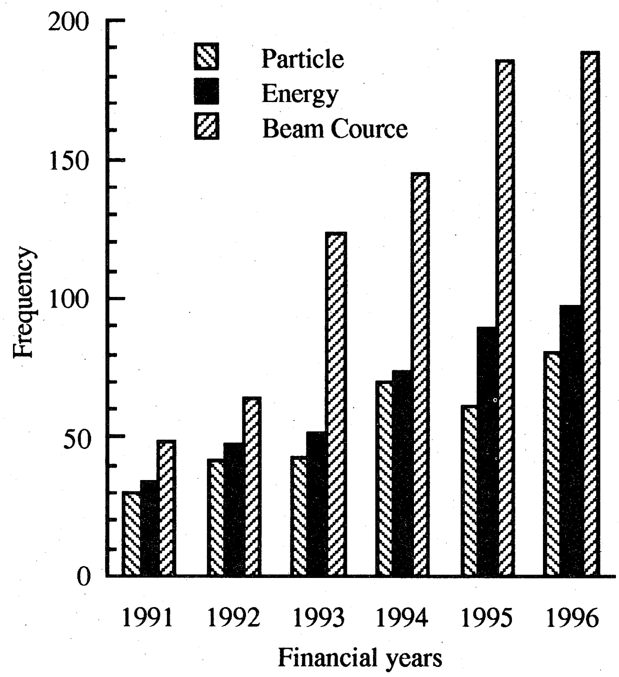

Fig. 3 Frequency of particle, energy and course change from 1992 to 1996.

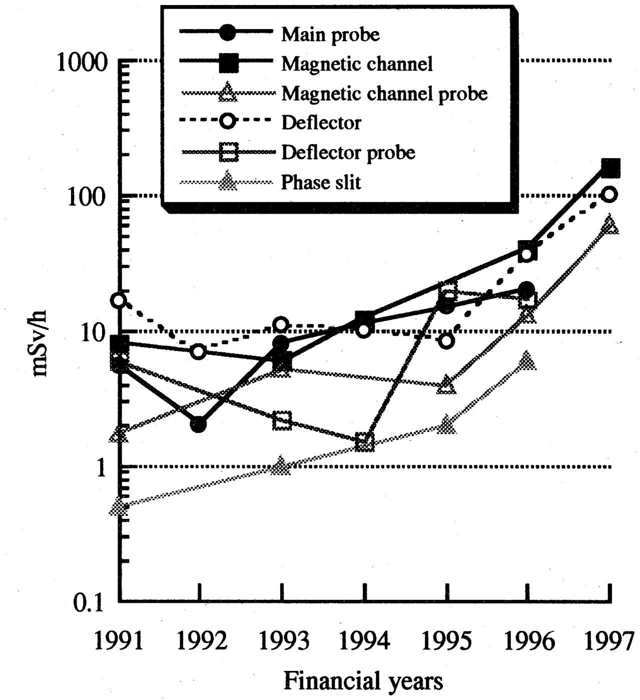

Fig. 4 Accumulation of induced radioactivity in the acceleration chamber of the cyclotron.

bility. Stability of the current outputted from the power supply is preserved by monitoring the voltage of the shunt resister. We have replaced the shunt resisters of the power supplies for the main magnet and the analyzing magnets. After replacement of the shunt resisters, the stability of the power supplies for the main magnet and the analyzing magnets is less than 10^{-5} for 8 hours and 4 hours, respectively. It is better than the stability before the replacement.

In a few years, we have had the following machine troubles:

(1) A high voltage of an ECR ion source broke down by increasing a humidity in the room.
(2) An inflector stem (about 150 kg weight) crashed on a cyclotron upper yoke from a stem carrier.
(3) A leakage from bellows, which are used for pressing the contact fingers of the movable shorting plate against the wall of the coaxial type resonator with high pressure air, caused a vacuum in the acceleration chamber worse.

The accumulation of induced radioactivity in the acceleration chamber is making it more difficult to conduct maintenance work inside the cyclotron. The strong sources of radiation are the electrostatic deflector (100 mSv/h) and the magnetic channel (160 mSv/h) as shown in Fig. 4. For the protection against radiation hazards, now it will be necessary to replace some of the strongly activated parts, such as main probe-head, magnetic channel and magnetic channel probe-head.

3 Beam Development

3.1 Cocktail beam acceleration

Cocktail beam acceleration is one of the most time-saving methods for changing the ion species and/or the energy. Ion "cocktail" which is composed of ions with the same or very close mass to charge ratio (M/Q), is produced in a ECR ion source, injected into the cyclotron, accelerated at the same time and extracted separately by a fine tuning of the magnetic field or a slight changing of the RF frequency.

The cocktail beam has been developed using ions with M/Q = 5: $^{15}N^{3+}$, $^{20}Ne^{4+}$, $^{40}Ar^{8+}$ and $^{84}Kr^{17+}$[3]. Particle identification was carried out by measuring a pulse height from an SSD. The results of the cocktail beam acceleration test are summarized in Table 1. The extracted beam current for 56 MeV $^{15}N^{3+}$, 75 MeV $^{20}Ne^{4+}$, 150 MeV $^{40}Ar^{8+}$ and 322 MeV $^{84}Kr^{17+}$ ions are 0.7, 1.0, 2.0 μA and 0.08 μA (electrical ampere) respectively. The time required for changing the ion species and/or energy is only one minute for the cocktail beam acceleration.

3.2 Extraction Current and Transmission

Particles accelerated and extracted so far are listed in Table 2. The extraction efficiency is defined by a ratio of the beam current measured with the main probe at r = 900 mm to that with the Faraday cup (FC) just after the cyclotron. The average extraction efficiencies for harmonic 1, 2 and 3

Table 1
Results of a cocktail beam acceleration tests.

Ion	Energy (MeV)	Frequency (MHz)	Extracted Intensity (eμA)
$^{15}N^{3+}$	56	13.867	0.7
$^{20}Ne^{4+}$	75	13.873	1.2
$^{40}Ar^{8+}$	150	13.881	2.3
$^{84}Kr^{17+}$	322	14.048	0.08

Table 2
Results of extracted intensity and overall transmission.

Ion	Energy (MeV)	Extracted Intensity (eμA)	Extraction Efficiency (%)	Overall Transmission (%)
H^+	10	12	80	27
	20	5	77	21
	30	5	67	22
	45	30	79	14
	50	5	44	14
	55	5	63	14
	60	5	57	22
	65	3	-	12
	70	5	42	12
	80	3	47	13
	90	10	48	7.7
D^+	10	11	29	3.7
	35	40	59	4.6
	50	20	49	7.2
$^4He^{2+}$	20	5.5	69	11
	30	1.4	42	10
	50	20	62	17
	100	10	32	10
$^{12}C^{5+}$	220	0.25	77	22
$^{16}O^{5+}$	100	1.7	34	8.1
$^{16}O^{6+}$	160	1.9	58	21
$^{16}O^{7+}$	225	0.2	54	10
$^{16}O^{7+}$	335	0.05	29	4.2
$^{20}Ne^{6+}$	120	1.6	53	18
$^{20}Ne^{7+}$	260	0.33	70	19
$^{20}Ne^{8+}$	350	1.5	63	23
$^{36}Ar^{8+}$	195	2.5	63	13
$^{36}Ar^{10+}$	195	0.1	43	1.2
$^{40}Ar^{8+}$	175	3	73	15
$^{40}Ar^{11+}$	330	0.6	86	20
$^{40}Ar^{13+}$	460	0.03	63	24
$^{84}Kr^{20+}$	520	0.05	72	20
$^{129}Xe^{23+}$	450	0.2	72	11

are 56%, 63% and 56%, respectively.

The overall transmission efficiency is defined by a ratio of the beam current with the FC just after the analyzing magnet at the injection line to that with the FC just after the cyclotron. The average transmission efficiencies for harmonic 1, 2 and 3 are 13%, 16% and 11%, respectively.

3.3 Measurements of Beam Phase

Time resolutions of a beam phase monitor were evaluated by a time-of-flight (TOF) measurement. The beam phase monitor[4] is a fast timing detector with a micro-channel plate (MCP). Secondary electrons emitted from a thin target, a 3 mm thick aluminum-strip, are collected into the MCP by an electrostatic field when ions pass through it. A flight time of an ion is determined using the beam phase monitor as a start counter and a plastic scintillation counter as a stop counter. TOF measurements have been carried out for 225 MeV $^{16}O^{7+}$ and 220 MeV $^{12}C^{5+}$ beams. The best overall time resolutions are 190 ps FWHM for 225 MeV $^{16}O^{7+}$ and 230 ps FWHM for 220 MeV $^{12}C^{5+}$.

3.4 Performance of ECR-18

An 18-GHz ECR ion source[5] was constructed to generate highly charge state ions and metal ions, and is now in test operation.

Modification of the microwave feeding and attachment of an aluminum plate to the inner surface of the plasma chamber resulted in increasing higher charge state ions, and Ar^{14+} was observed. Iron ion generation was tested by means of MIVOC (Metal Ions from VOlatile Compounds). We used vapor of ferrocene $Fe(C_5H_5)_2$ to release Fe elements into the plasma chamber and observed Fe^{15+}. Nickel ion generation from a ceramic rod of nickel oxide (NiO) was carried out and we observed Ni ions with charge state up to 16+ as shown in Fig. 5. Replacing the rod support made of conductive material with non-conductive one, we will obtain higher charge state ions.

After completion of the development, the ion source will be connected to the cyclotron.

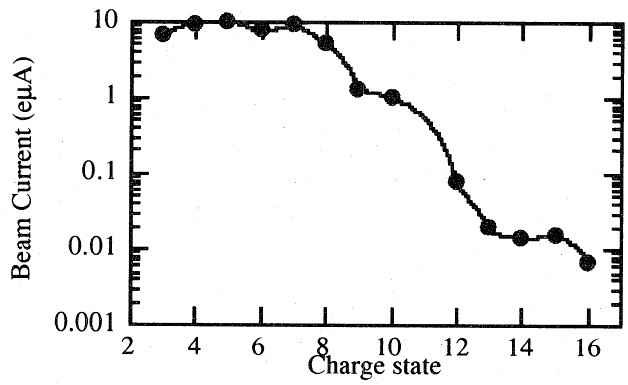

Fig. 5 Charge state distribution of Ni ion.

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